

Low NO_x Combustion Systems for Minimizing NO_x and Fly Ash LOI: Wall-Firing Petcoke and T-Firing Severe Slagging Coal

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ABSTRACT

One of the challenges faced by suppliers of low NO_x combustion equipment is to not only achieve significant reduction in NO_x, but to also prevent an increase in fly ash LOI. Advanced Burner Technologies (ABT) has developed low NO_x combustion systems for both wall and T-fired boilers that yield significant NO_x reduction without increasing fly ash LOI. In some cases, retrofit of ABT's system has actually resulted in a decrease in LOI. Two pertinent case studies are presented.

The St. Johns River Power Park is a two-boiler, 2 x 660 MW station that fires a blend of 80% Colombian coal and 20% delayed petroleum coke. These Foster Wheeler boilers were equipped with 28 OEM low NO_x burners in an opposed wall-fired configuration. NO_x emissions were typically in the high 0.4 lb/10⁶ Btu range and LOI in excess of 30% for normal operation with a top row of front wall burners out of service. ABT provided a complete retrofit of 28 fuel injectors and an OFA system for Unit 2 in the spring of 2004. NO_x emissions have been reduced to approximately 0.3 lb/10⁶ Btu and LOI to about 20% for Unit 2 firing the fuel blend.

In early November 2004, St. Johns Unit 2 modified operation with one row of front wall burners firing 100% petroleum coke and the other five rows firing 100% coal. With only minor burner adjustments, stable flames were achieved for the burners firing petcoke without requiring oil support. This firing configuration resulted in a reduction in fly ash LOI to 12 – 15%, due to improved fineness for the mill firing petroleum coke.

Owensboro Municipal Utilities' (OMU) Elmer Smith, Unit 2, is a 290 MW Combustion Engineering T-fired unit that fires a variety of high sulfur Midwestern coals. A NO_x level in the low 0.4 lb/10⁶ Btu range was achieved with the existing ICL close couple overfire air system. In April 2003 ABT installed new T-fired low NO_x burners and a separated overfire air (SOFA) system. The NO_x emissions are now less than 0.25 lb/10⁶ Btu with no deterioration in boiler performance or efficiency. Unburned carbon has not increased and is consistently less than 1% even though excess air has been reduced from approximately 20% to 15%.

ST. JOHNS RIVER POWER PARK

Background

These 660 MW opposed-fired units each have 28 burners that are supplied by seven mills. Figure 1 illustrates the configuration of the two boilers. The seven burner elevations are arranged four on the front wall and three on the rear wall. Each elevation has four burners, supplied by one pulverizer.

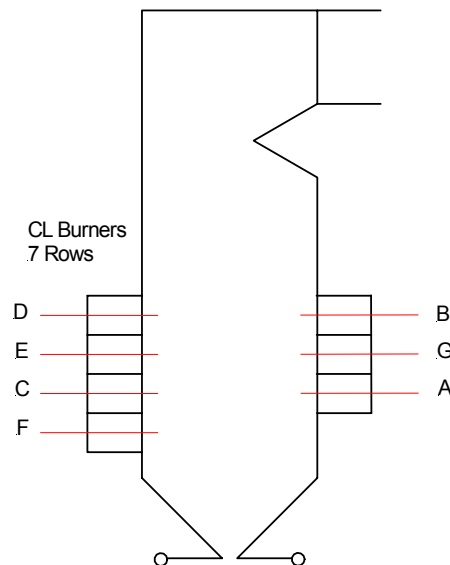


Figure 1 Boiler Configuration for St. Johns Units 1 and 2

Beginning in 1997, St. Johns River Power Park began firing a blend of 80% bituminous coal and 20% delayed petroleum coke, in order to realize a significant reduction in fuel costs. To meet a NO_x limit of $0.5 \text{ lb}/10^6 \text{ Btu}$, the boilers typically operated with the top row of burners on the front wall out of service during full load operation. The air flow was maintained through the secondary air registers of the out of service burners to achieve a simulated overfire air effect. Due to the low volatile content of the petroleum coke in the blend, incomplete combustion was a problem, with both boilers suffering from high CO emissions and fly ash LOI. This problem was exacerbated when Colombian coal was fired in the fuel blend, since it is commonly known to be a hard to burn coal. As a result of this poor combustion, furnace sidewall corrosion has been an ongoing problem at St. Johns, due to the presence of reducing conditions along the sidewalls. Flame stability problems were also encountered at St. Johns with the OEM low NO_x burners, especially the bottom rows of burners.

ABT provided a complete retrofit of Opti-Flow™ fuel injectors for both boilers at St. Johns. Unit 1 was retrofitted with a full complement of fuel injectors in the spring of 2003. NO_x emissions were reduced by over 20%, based on the average of tests conducted with seven different mills out of service.² CO emissions were lowered to less than 10 ppm, compared to an average of nearly 300 ppm for normal operation with the top row of front wall burners out of service.

The new fuel injectors and windbox modifications for balancing secondary air flow resulted in approximately 50% reduction in LOI. However, LOI was still relatively high (~20%).

For Unit 2 ABT completed the retrofit of fuel injectors plus installation of an OFA system in the spring of 2004. NO_x was reduced to the guarantee level of 0.3 lb/10⁶ Btu for operation with either of the top rows of burners out of service. CO emissions were less than 200 ppm, but fly ash LOI was still relatively high and in the low 20% range.

Fuel Properties

Table 1 shows the analyses of the delayed petcoke, Colombian El Cerrejon coal and a fuel blend of 20% petcoke and 80% bituminous coal by weight. As shown in Table 1, the volatile content of the petcoke is less than 10%, which is typical for delayed coke. The Colombian coal is high volatile and does not appear to be a hard to burn fuel based on the proximate and ultimate analyses. The blended fuel has an average volatile content that is relatively high; however, these average fuel properties cannot be used to characterize the blend since each fuel burns as discrete particles.

Table 1 Petroleum Coke, Coal and Blend Analyses

	Delayed Pet. Coke	Colombian Coal	20% Coke 80% Colombian
Prox. Analysis			
Fixed Carbon	83.92	47.60	54.87
VM	8.50	33.40	28.42
Ash	0.52	7.40	6.02
Moisture	7.06	11.60	10.69
Total	100.00	100.00	100.00
Ult. Analysis			
Carbon	82.22	66.54	69.67
Hydrogen	3.35	4.50	4.28
Oxygen	0.00	7.99	6.40
Nitrogen	1.71	1.32	1.40
Sulfur	5.14	0.65	1.54
Ash	0.52	7.40	6.02
Moisture	7.06	11.60	10.69
Total	100.00	100.00	100.00
HHV, Btu/lb as rec'd	14,200	11,800	12,280
HGI	44	48	

The Hargrove Index for each fuel is also shown in Table 1. Both fuels have relatively low HGI's less than 50. Consequently, these hard to grind fuels provide a real challenge for vertical mills such as those used at St. Johns.

Thermogravimetric Analysis (TGA) is a simple laboratory technique for assessing the reactivity of fuels. Figure 2 shows the TGA burning profiles of these fuels along with that of a Kentucky coal sometimes fired at St. Johns. As shown in this figure, the petcoke has a significantly higher temperature at which devolatilization/ignition occurs, due to its low volatile content. However, the petcoke does burn out rather easily in this test that uses a <200 mesh sample. On the other hand, the Colombian coal shows a protracted burning profile and a relatively high temperature for completion of combustion. As mentioned earlier, the low char reactivity for this fuel cannot be identified by the proximate/ultimate analyses. Boiler experience has shown that the coals from this region often yield relatively high fly ash LOI. This poor reactivity has been attributed to rather inert, high carbon fractions of the coal that formed from a high heat environment during the coalification process³.

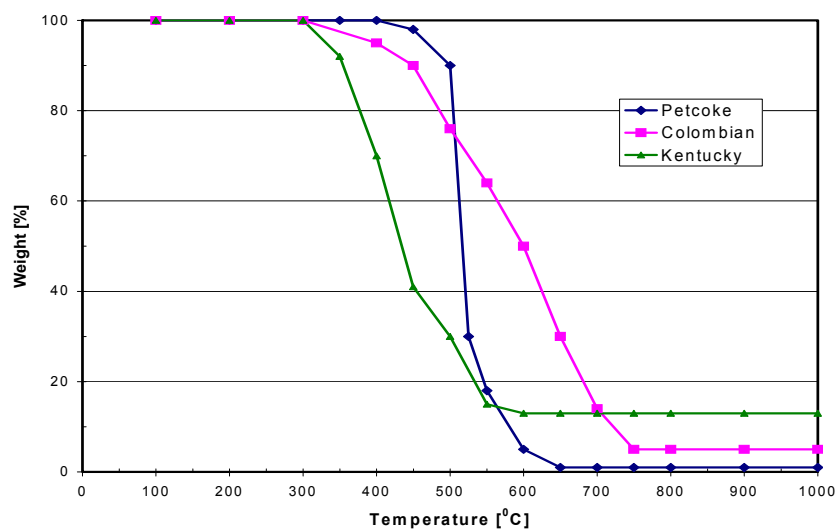


Figure 2 TGA Burning Profiles of Fuels Fired at St. Johns

As shown above, the petcoke and Colombian coals both present different challenges from a combustion standpoint. The low volatile content of the petcoke can lead to flame stability problems, while the poor reactivity of the Colombian coal can produce high fly ash LOI. These fuel properties present a particular challenge when they are fired in a low NO_x combustion system with OFA.

The Opti-Flow™ Mark II Low NO_x Burner

A new low NO_x burner, developed by Advanced Burner Technologies, began commercial operation in 1997 and has since been installed on numerous large utility steam generators. Some of the boilers were upgraded from the OEM-supplied LNB's to ABT's Opti-Flow™ low NO_x fuel injector design; complete low NO_x burner replacement was undertaken on other boilers. When firing bituminous coal, NO_x was reduced up to one-third from the levels emitted by the OEM's low NO_x burners, while UBC remained in the same range as previously attained^{4,5}. When firing PRB and lignite, the Opti-Flow™ burner has yielded NO_x levels 40 to 50 percent below those of the original low NO_x burner^{5,6,7}.

ABT utilizes a highly effective low NO_x fuel injector as the primary NO_x control element. Burner line fuel/air balance, coal fineness, windbox air distribution, etc, all affect NO_x reduction by detracting from the optimum fuel/air ratio at the burner. Optimizing these variables allows the low NO_x burner to operate as intended. The more sophisticated the burner design, the more effective will be the optimization of the non-burner variables.

The key features of the ABT Opti-Flow™ fuel injector have been discussed before in detail with regards to St. Johns². The following is a summation of its salient features and benefits:

- Opti-Flow™ low NO_x segmented nozzle with external stabilizers; there are no internal obstructions to the free passage of coal. Nearly uniform distribution around the burner nozzle circumference is obtained, which provides significant aid in simultaneously attaining minimum NO_x and UBC.
- A highly stable, very bright flame is produced that is also adjustable. This enhanced flame stability is extremely important when firing hard to ignite petcoke. An inner secondary air zone damper and fixed vane swirler are mounted to the fuel injector. The damper is adjusted to vary the ratio of airflow between the inner and out air zones, with manual adjustment made during burner optimization.
- In some cases, conversion of the existing low NO_x burners to the Opti-Flow™ configuration requires only the installation of the Opti-Flow™ fuel injector inside the existing dual register.

Figure 3 is an illustration of the Opti-Flow™ Mark II fuel injector.

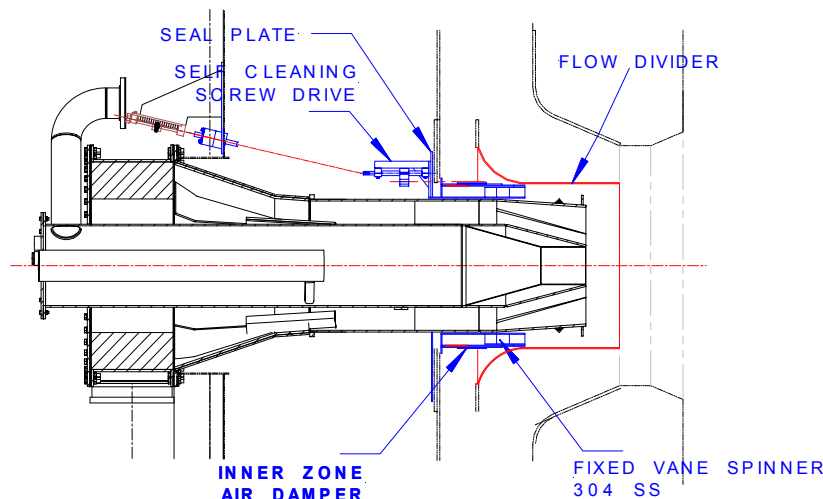


Figure 3 Schematic of St. Johns Opti- Flow™ Mark II Fuel Injector

ABT Aerodynamic OFA System

Overfire air port design has evolved from single stage ports, such as circular or rectangular openings with air flow controlled by a single damper per port, to dual staged ports with an axial flow internal section and a swirled outer throat. Although these latter designs utilize various types of flow splitters and control dampers, they have one aspect in common: all use circular concentric dual throats. The axial air flow through the central throat is for penetration into the center of the furnace and the air flow through the outer throat swirls with the intention of creating near zone mixing between the OFA flow and the gases rising between the burner columns.

None of these conventional OFA port designs actually cause the air flow to spread out sideways, to cover the zone between adjacent burner columns. In practical operation these designs do not produce full coverage across the furnace plan area, primarily because swirled air flow on one side of the port is given upward flow direction while the other side's flow is downward. An alternative design is needed to adequately address this situation, especially when firing fuels that are difficult to burnout such as Colombian coal.

Advanced Burner Technologies has responded to shortcomings in OFA port design by developing a non-circular, two-stage port design that creates both an axial flow field along the port's axis, for good penetration, and horizontally translated flow between adjacent ports for coverage of the gases laning between burner columns. A schematic of the ABT OFA port is shown in Figure 4.

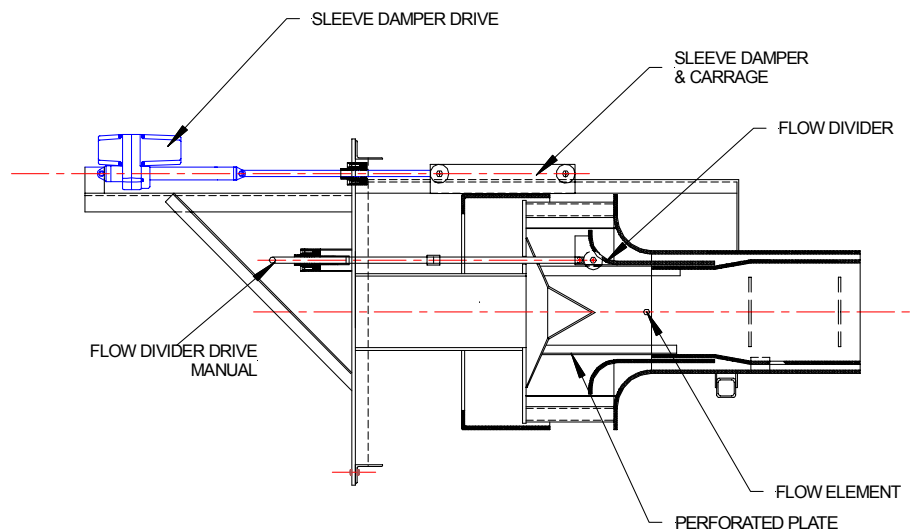


Figure 4 Two-Stage Overfire Air Port

At St. Johns OFA ports are located above each burner column on both the front and rear walls. Only a single damper is required to control the quantity of air flowing into the port: the air distribution is accomplished aerodynamically. When the ports are operating within their design flow range, the penetration and horizontal mixing effects

are automatic: operators only set the quantity of air flow based on NO_x and CO levels. The near zone mixing can be varied by adjusting the proportion of inner air to outer air with a simple damper. This feature enhances the inherent side-to-side recirculation zones to yield greater coverage across the furnace plan. Figure 5 shows the excellent penetration and achieved with the ABT OFA port design in a CFD model. In order to burn out the products of combustion rising along the sidewalls, a novel wing port is also used to blanket the sidewalls with air.

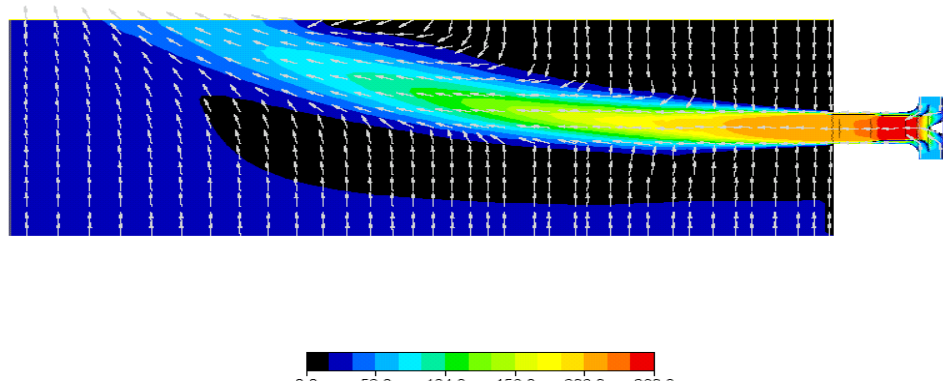


Figure 5 ABT Overfire Air Port Penetration

St. Johns Unit 2 Post Retrofit Results

Petcoke and Colombian Coal Blend Firing

Figure 6 shows the NO_x emissions before and after the complete retrofit of 28 ABT fuel injectors and OFA system. Prior to windbox modifications by ABT in 2002, a severe secondary air imbalance resulted in higher air flow to the D (top front) row of burners.

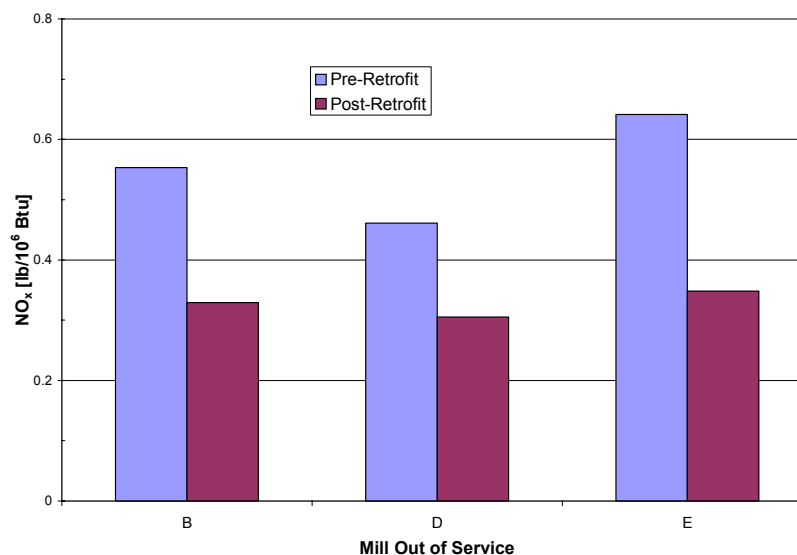


Figure 6 St. Johns Unit 2 NO_x Emissions Before and After Retrofit

In order to maintain NO_x below the limit of 0.5 lb/10⁶ Btu, a simulated OFA effect was established by keeping the secondary air register open when the D row of burners were out of service. However, this configuration resulted in CO emissions of greater than 500 ppm².

As shown in Figure 6, NO_x was lowered by approximately 35% for the configuration with D-Mill out of service after the complete retrofit of burners and installation of the OFA system. CO emissions were lowered to less than 200 ppm and LOI was reduced by about 50% for operation with D-Mill out of service. NO_x emissions were reduced by approximately 50% for the other mill configurations as shown in Figure 6.

Fly ash LOI was still relatively high (~20%) even though it was reduced by approximately 50% following retrofit of the ABT fuel injectors and OFA system. This high fly ash LOI can be attributed to both fuel properties and poor mixing of the petcoke and coal that resulted in poor mill performance.

As shown earlier, both fuels have relatively low grindability with the petcoke having a HGI of only 44. Mill fineness was found to improve when the petcoke was fired separately from the coal. The amount of material greater than 50 mesh increased from 99.4 to 99.8%, while the material passing 200 mesh increased substantially from 65.8 to 75.6%.

100% Petcoke Firing in a Single Burner Row

Following the fall 2004 outage, a test burn was conducted with the C-Row (second from bottom) of burners firing 100% petcoke and the remaining firing 100% Colombian coal. In this configuration, the C-Row burners were supported from flames below by the F-Row burners. The E-Row of burners directly above the C-Row was out of service (see Figure 1). The fuel flow to each of the mills was adjusted such that the petcoke input was approximately 18% on a fuel weight basis.

As shown in Table 2, fineness improved while firing the fuels separately instead of a blend. This improvement can be attributed to better grindability when the fuels are ground in separate mills. In some cases, the grindability of a fuel blend can be lower than the average of the two HGI's, with the lower HGI fuel producing oversize material.

Only slight burner adjustments were required to stabilize the flames for the 100% petcoke. Figure 7 compares the flames for a burner firing petcoke with that of one firing Colombian coal at full load. As shown in this figure, the petcoke flame is slightly less intense than the coal flame; however, it is well-rooted in the burner throat.



100% Petcoke



100% Colombian Coal

Figure 7 Petcoke and Colombian Coal Flames at Full Load

NO_x emissions were 0.4 lb/10⁶ Btu with this configuration firing the fuels from separate mills. This NO_x level is somewhat higher than that shown in Figure 6 for operation with the E-Mill out of service. However, for this test the OFA was set at less than 50% of the design flow as a safeguard to ensure good combustion. Considering the excellent flame stability achieved in this test, higher levels of OFA could be used to lower NO_x without compromising flame integrity. CO emissions were less than 50 ppm and did not increase when firing the fuels from separate mills.

Reduced LOI was one of the greatest impacts on boiler performance with separate firing of the petcoke and coal. As shown in Figure 8, fly ash LOI typically ranged from 18 to 25 when the fuels were cofired in the same mills. LOI was reduced to 12 to 15% when the petcoke and coal were fired in separate burners. Thus, it appears that oversize petcoke was responsible for the high LOI when the fuels were fired as a blend. As shown earlier in Figure 2, petcoke is a difficult fuel to ignite but not so hard to burn out when it is ground relatively fine. Since petcoke lacks porosity and internal surface area, it is difficult to burn out when fired as relatively coarse particles.

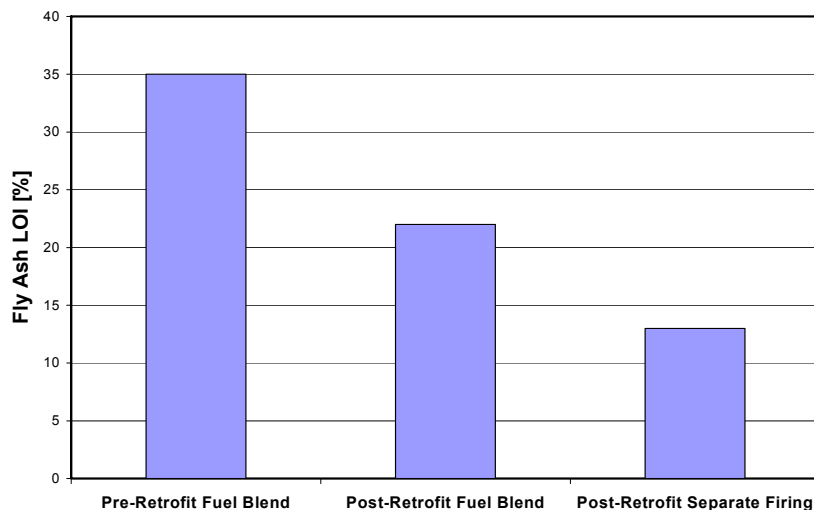


Figure 8 Fly Ash LOI from Fuel Blend and Separate Firing

OMU ELMER SMITH UNIT 2

Background

OMU began investigating means of reducing NO_x levels from Unit #2 to meet a stack emission level of 0.15 lb/10⁶ Btu; the goal was to meet this level without the use of an expensive SCR system. Bidders unable to achieve an emission level below 0.20 lb/10⁶ Btu were not considered by OMU. In 2002, OMU received proposals for several competing systems ranging from 0.15-0.19 lb/10⁶ Btu:

- Deep staging the furnace with boosted overfire air and aqueous ammonia injection in the upper furnace,
- Burner modifications coupled with combustion tempering and overfire air in combination with urea rich reagent injection and SNCR, and
- New low NO_x burners and advanced overfire to minimize furnace NO_x followed by anhydrous ammonia SNCR.

The latter approach was chosen as the best technical solution and most cost-effective means of achieving the emission goals without deteriorating the furnace performance. The new burner and overfire air system would be designed to reduce the NO_x to below 0.25 lb/10⁶ Btu followed by the SNCR system which would reduce the NO_x to below 0.15 lb/10⁶ Btu. The SNCR system was installed in 2003 and OMU purchased ABT's low NO_x combustion system for installation in Spring 2004 for operation during the 2004 ozone season. Although this was ABT's first T-fired retrofit, the confidence level for success was high due to ABT's successes with numerous wall-fired retrofits and the fact that the wall-fired burner design would be adapted to the corner-fired configuration.

The two primary considerations were the high heat release of the furnace and the fuel constituents: high sulfur and very high slagging potential. ABT addressed this by incorporating a proprietary means of protecting the walls.

Included in the work scope were CFD models of the furnace and secondary air supply system. Reaction Engineering Incorporated (REI) performed the former and Airflow Sciences Corp (ASC) performed the latter.

ABT's T-Fired Low NO_x Combustion System

The wall-fired burner concepts were translated to the vertical configuration of the corner-fired boiler. The OEM fuel injector was replaced with the Opti-Flow™ design, including the inner secondary air zone with fixed vane swirler and flow divider, but the existing air flow controls were retained: fuel/air and auxiliary air compartments and dampers.

Figure 9 illustrates the design of the fuel injector several of these fuel injectors and several during fabrication for Elmer Smith Unit #2. It is essentially identical to the wall-fired design, including the inner zone, but includes a tilt feature made possible by a unique ball fit joint and the fuel air seal arrangement.

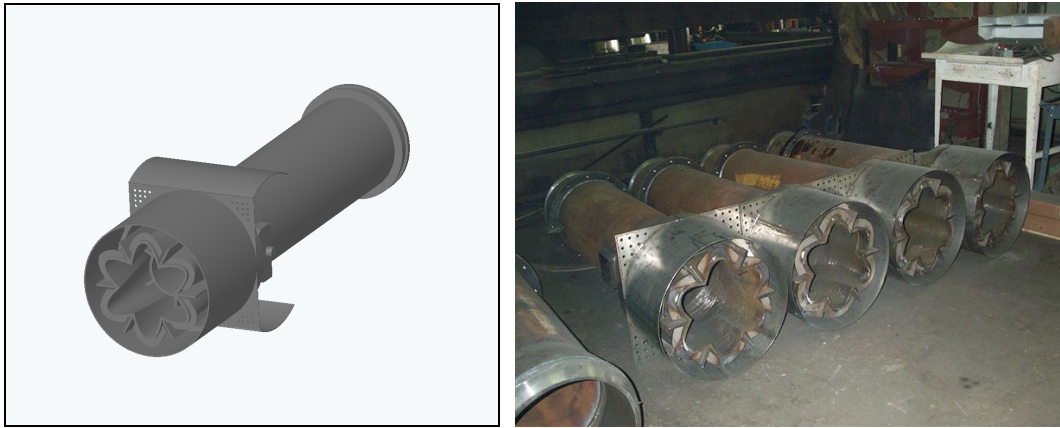


Figure 9 Opti-Flow™ Fuel Injector for Corner-Fired Boiler

Figure 10 illustrates the furnace corner and the relationship between the fuel injectors and auxiliary air injectors for Elmer Smith Unit #2. The unit is four levels high supplied by four mills, for a total of 16 burners. Each new fuel injector was installed at the same level as the existing burners; no changes in coal piping were necessary. Further, the existing OEM sweep elbows were used, however ABT's fuel distributors were installed to achieve controlled fuel distribution into the fuel injector nozzles.

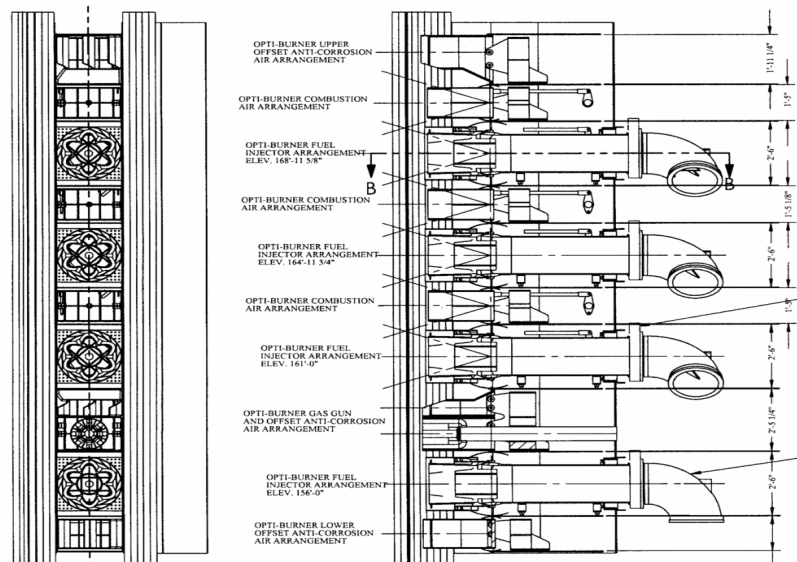


Figure 10 Corner Configuration for Elmer Smith Unit #2

Figure 11 illustrates the two-stage port design used. A bell-mouth divides the flow between the inner and outer passageways; total flow control is via a sleeve damper (not shown) when all ports are supplied by a common windbox, or via a separate damper for any port that may be within an individual windbox.

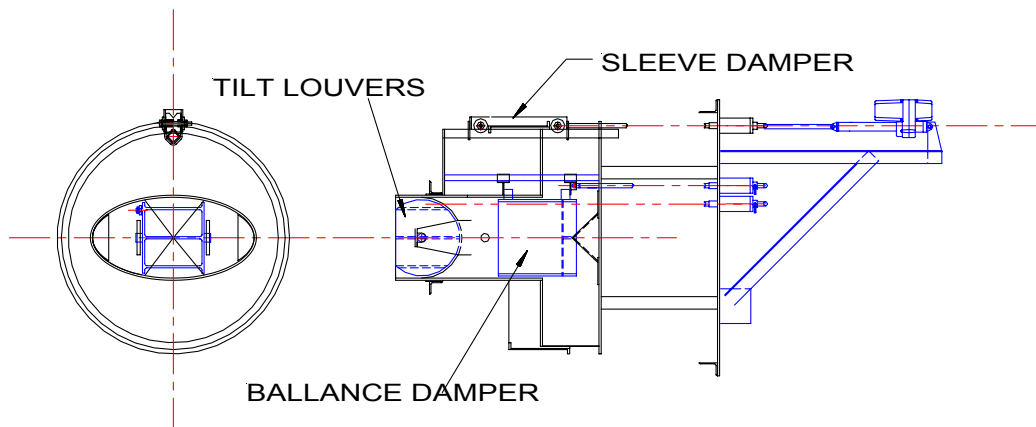


Figure 11 Two-Stage Aerodynamic Staging Port with Tilt Feature

Figure 12 illustrates the air staging system design arrangement for this unit. The ports are located in an unconventional manner: two on each wall off-set from the centerline. This results in the most effective mixing on a corner-fired unit. Only one level of OFA is required with the ABT system, due to the excellent penetration and mixing achieved with the aerodynamic, two-stage port.

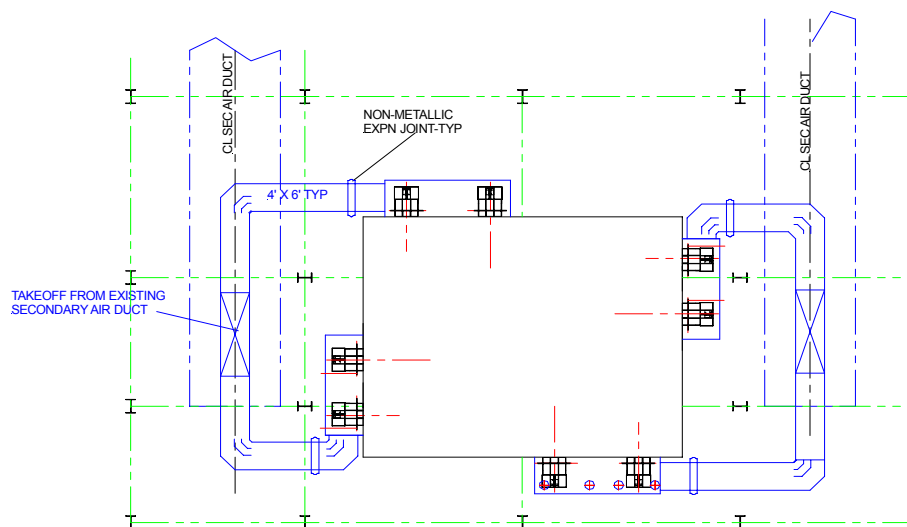


Figure 12 Plan View of OFA Arrangement for Elmer Smith Unit #2

Post-Retrofit Results

Prior to the low NO_x combustion system retrofit, testing was conducted to measure baseline NO_x , CO and fly ash LOI. Following commissioning and combustion tuning, boiler performance testing showed that all guarantees were met. The baseline and retrofit testing were conducted at approximately 50%,

75% and 100% boiler MCR. A comparison of the post-retrofit with the baseline results is given below.

NO_x Emissions

Baseline NO_x emissions are shown in Figure 8 at different boiler loads. As shown in this figure, baseline NO_x emissions were 0.426 lb/10⁶ Btu at full load. For tests at the three different load levels, the lowest NO_x was observed at approximately 75% of MCR. Post-retrofit tests indicated a slight increase in NO_x with boiler load as shown in Figure 13. The NO_x guarantee of 0.25 lb/10⁶ Btu was also met at all three boiler loads.

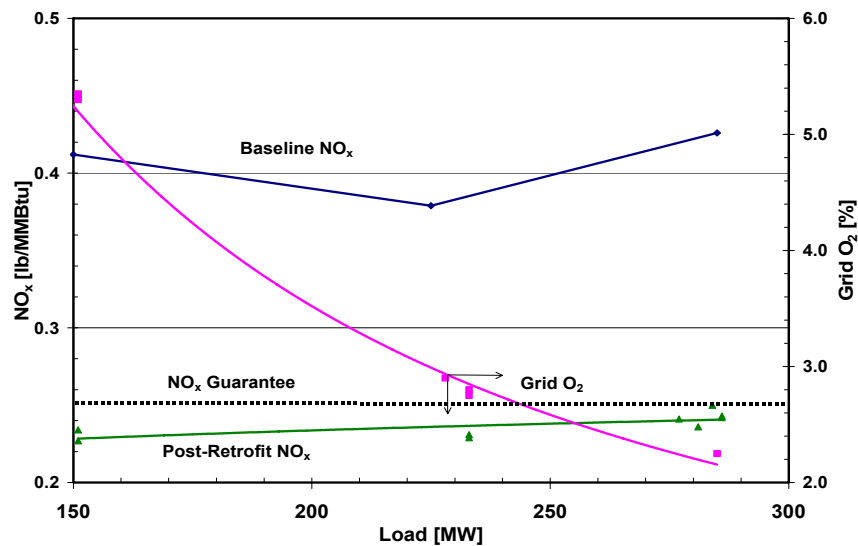


Figure 13 Baseline and Pre-Retrofit NO_x vs. Boiler Load

The post-retrofit NO_x data shown in Figure 8 was obtained from testing with lower than design OFA flow. In order to achieve minimum NO_x, OFA flow was increased to the design value. With this OFA flow, NO_x was reduced to 0.227 lb/10⁶ Btu at full boiler as shown in Figure 14. This NO_x level corresponds to a reduction of approximately 47% compared to baseline levels at full load.

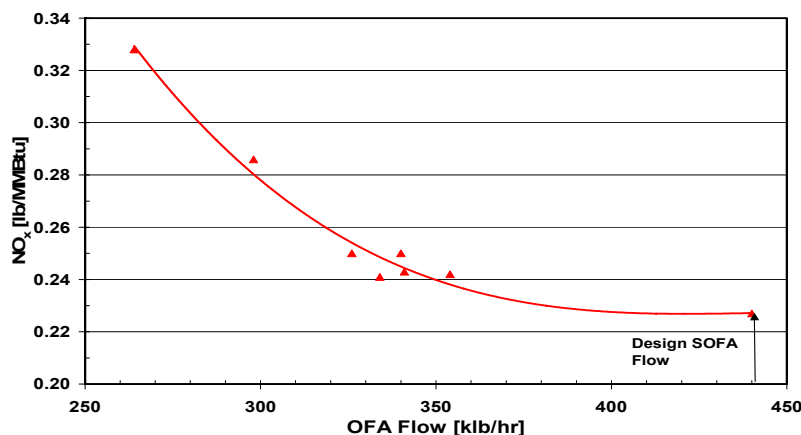


Figure 14 NO_x vs. OFA Flow at Full Boiler Load

CO Emissions

Figure 15 compares the baseline and post-retrofit CO emissions versus boiler load. Baseline CO emissions were very low and less than 20 ppm. CO emissions were slightly higher after retrofit of the ABT low NO_x combustion system. However, the CO guarantee of 100 ppm was met at all three boiler loads. These low CO emissions are especially significant considering the high level of NO_x reduction that was achieved.

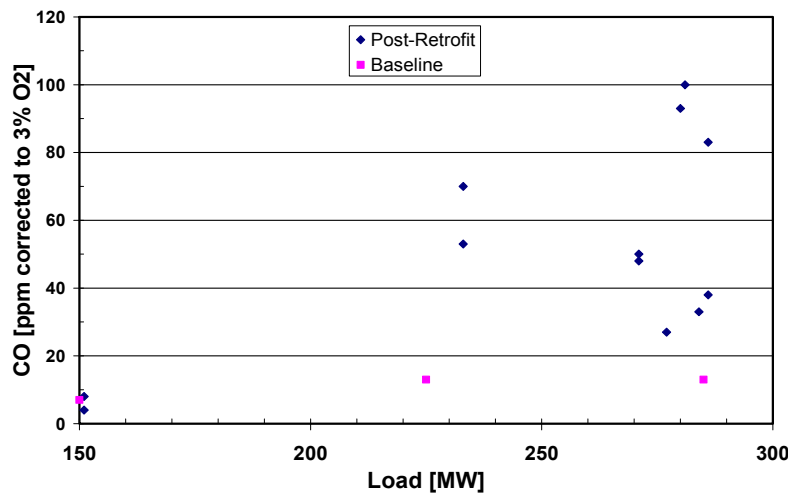


Figure 15 Baseline and Pre-Retrofit CO Emissions vs. Boiler Load

Fly Ash LOI

Fly ash LOI values for baseline and post retrofit are shown in Figure 16 for different boiler loads. As shown in this figure, the LOI was only slightly higher after retrofit of the ABT low NO_x combustion system. However, the LOI increased by less than 1% for the different boiler loads and the guarantee was easily met.

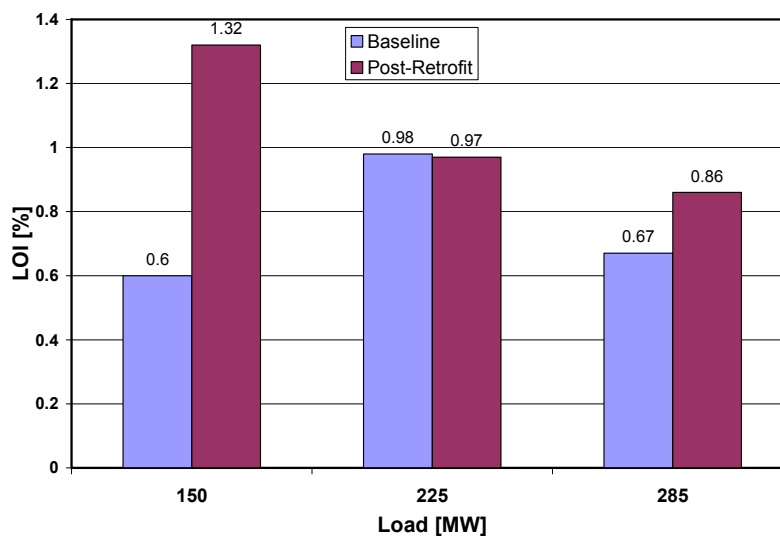


Figure 15 Fly Ash LOI vs. Boiler Load

It should also be noted that no increase in LOI was observed even though excess O₂ was reduced from approximately 3% to 2% with the retrofit of the ABT low NO_x combustion system.

Furnace Slagging

The high sulfur coal fired at OMU has very high ash (15.9%) and iron contents (21.3% Fe₂O₃ in ash) that make it prone to slag; ash softening temperature (reducing) is relatively low and only 2170°F. In fact, this coal is also fired in Elmer Smith Unit #1, a cyclone boiler, since it has such a high slagging propensity. The ability to burn these coals is paramount to OMU's success as a low cost energy provider being ranked among the lowest cost plants in the United States.

Prior to the retrofit, furnace slagging was a serious operational problem for Elmer Smith Unit #2 as noted above. Severe slag build-up required the unit to drop load to shed slag as often as each shift. In addition, burners in some of the corners of the furnace were frequently not able to tilt due to excessive slagging. Since retrofit of the ABT combustion system, the unit slagging has practically been eliminated with nightly load dropping no longer being required to shed slag.

Summary

ABT has developed a low NO_x combustion system for both wall and T-fired boilers that not only achieves minimum NO_x, but also yields similar or lower fly ash unburned carbon than OEM low NO_x burners. These results can be attributed to two features of the ABT low NO_x combustion system. First, the Opti-Flow™ burner produces a very intense flame that reduces NO_x and also promotes rapid combustion of the fuel carbon. Second, the aerodynamic OFA system completes combustion of the unburned carbon in the combustion gases due to the deep penetration and horizontal mixing of the air.

Two 660 MW boilers at St. Johns River Power Park have been completely retrofitted with ABT's Opti-Flow™ fuel injector and windbox modifications for equalizing burner air flow. Unit 2 has also been retrofitted with ABT's aerodynamic OFA system. For Unit 2, the guarantee NO_x level of 0.3 lb/10⁶ Btu has been met for operation with a top row of burners out of service. CO emissions have been lowered from several hundred ppm to less than 100 ppm on both boilers. LOI has also been reduced by 30 to 50% for both units to 20 - 25%.

Extremely stable flames and increased turndown capability was achieved after retrofit of the ABT fuel injectors, while firing the typical fuel blend of 80% Colombian coal and 20% petcoke. As a result, a test was conducted to verify the potential of firing 100% petcoke in a row of burners on Unit 2. This firing configuration was found to provide increased fineness due to better grindability of the petcoke when fed alone to the mill. As a result, fly ash LOI was reduced to 12 to 15%. For this test NO_x emissions were slightly higher than operation with

the fuels fired as a blend, since the OFA flow was lowered to less than 50% of design. CO emissions were less than 50 ppm. The unit has been operating continuously in this mode since early November 2004.

ABT has successfully implemented its novel low NO_x combustion system for T-firing at Owensboro Municipal Utilities' Elmer Smith Plant, Unit #2. This technology was developed based on the unique features of ABT's wall-fired system that has been retrofitted to numerous boilers. This retrofit project provided two major challenges: high heat release of the furnace and a high sulfur, severely slagging fuel. ABT met these challenges by developing a novel fuel injector and combustion air design and incorporating a proprietary means of protecting the walls. The following summarize the results of this project:

- NO_x emissions are below the guarantee level of 0.25 lb/10⁶ Btu at loads ranging from 50% to 100% MCR. At full load NO_x levels less than 0.23 lb/10⁶ Btu were attained.
- CO emissions are less than the guarantee of 100 ppm over the load range.
- Fly ash LOI is consistently less than 1% even with a reduction in excess air from 20% to 15%.
- Furnace slagging has been practically eliminated. The unit now does not require frequent load dropping to shed slag.

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